Contrails

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One of the most visible signs of human influence on the atmosphere is the condensation trail, or contrail, formed behind high altitude aircraft. This anthropogenic cirrus cloud can occur as a single line or in imposing geometrical formations as clusters of criss-crossing or parallel lines, Like natural cirrus clouds, contrails are composed of ice crystals and can produce the same dramatic optical displays, especially around sunrise or sunset. Persistent contrails also play a role in climate because they reflect sunlight and trap infrared radiation just like their naturally formed cousins. Thus, the presence of a contrail cluster in an otherwise clear sky can diminish the amount of solar energy reaching the surface during the daytime and increase the amount of infrared radiation absorbed in the atmosphere at all times of day. These opposing effects can simultaneously cool the surface and warm the air within the troposphere. Currently, the overall impact appears to be a warming effect, but research is continuing to unravel the role of this phenomenon in climate change.

The only difference between natural cirrus clouds and contrails is their origin. Natural cirrus clouds typically require an excessive amount of humidity to form out of thin air. Amorphous, liquid water droplets readily form when the relative humidity slightly exceeds 100%, the saturation or dewpoint. At temperatures below freezing, ice clouds can exist at lower humidities because the thermodynamic relationship between the solid and gas phase differs from that between the liquid and gas phase of water. However, extra water vapor is needed to enable the gas molecules to line up in the regular formation of an ice crystal lattice. Most natural cirrus clouds form at humidities near or above the dewpoint, usually as a result of forming a water

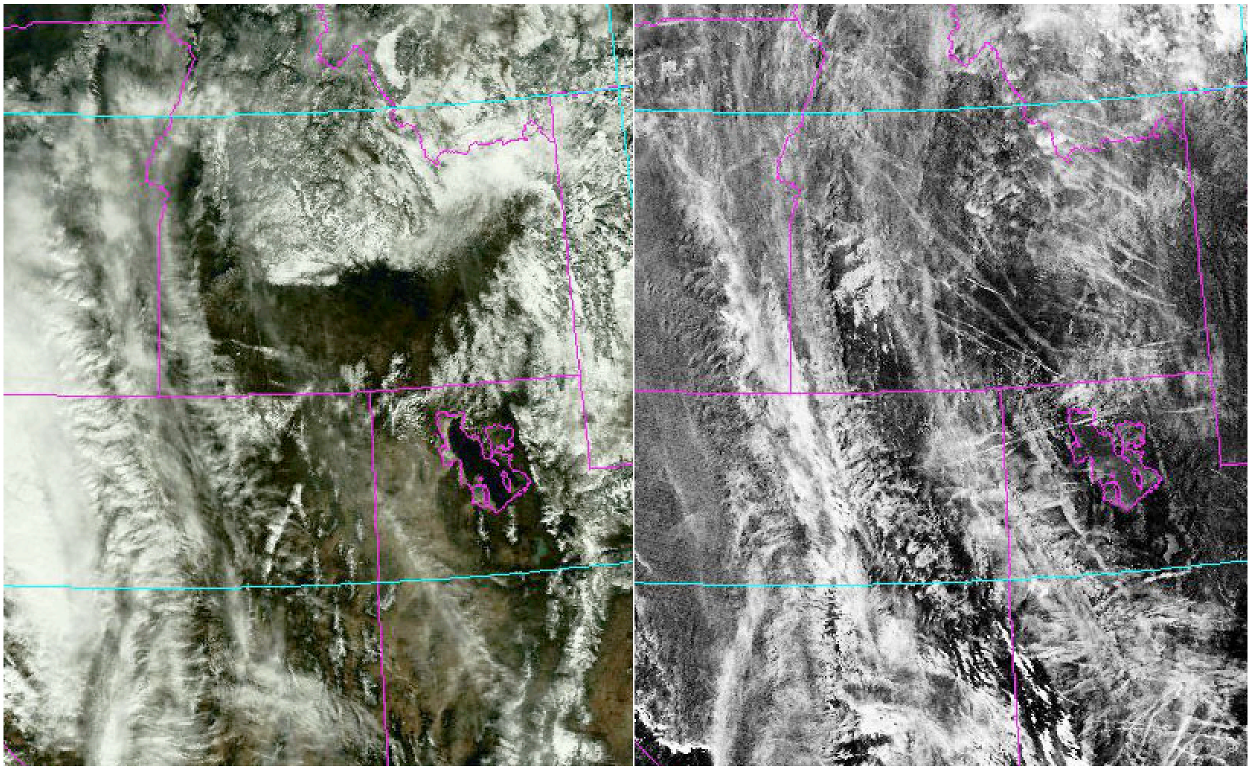
droplet first. Once formed, the ice crystal can grow, even at lower humidities because less water vapor is needed. Thus, the cold atmosphere at high altitudes can often support the existence of a cirrus cloud but is not moist enough to form one.

When the temperature is less than about -39°C and the conditions are right for cirrus to exist, aircraft exhaust can short circuit the natural cirrus formation process. The mixture of the ambient air with the water vapor in the exhaust temporarily raises the humidity above the dewpoint causing initiation of a multitude of tiny ice crystals. If the humidity is high enough, the crystals continue growing and the contrail spreads. Otherwise, it dissipates rapidly or gradually depending on the relative humidity. Persistent contrails can often grow into natural-looking cirrus clouds within a few hours, a phenomenon that is best observed from space. Although they typically only last a 4 - 6 hours , some clusters have been observed to last more than 14 hours and travel thousands of kilometers before dissipating. These persistent contrails are estimated to have caused cirrus cloud cover to rise by 3% between 1971 and 1996 over the United States of America and are well-correlated with rising temperatures.

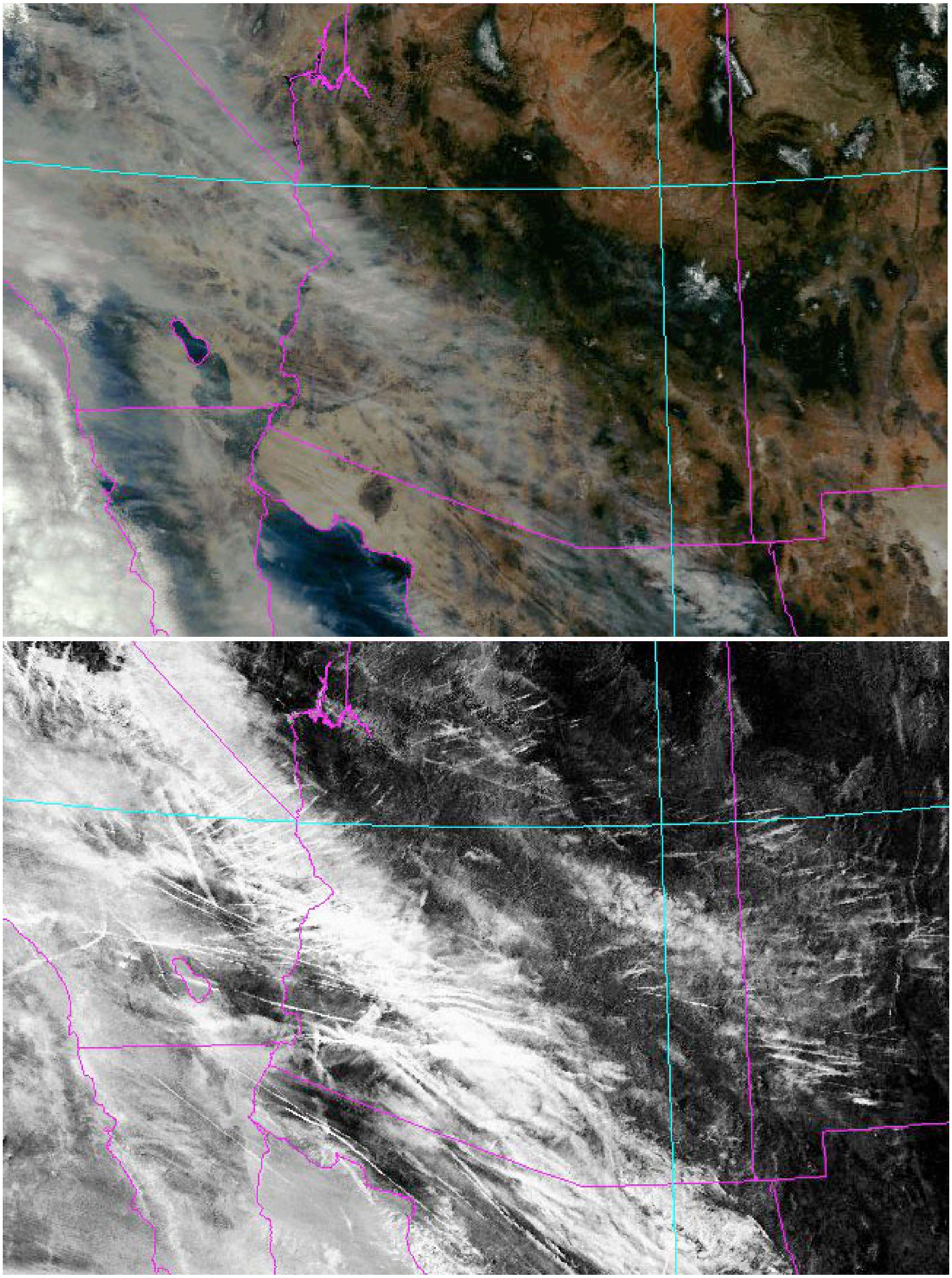
Increasing air traffic in nearly every other country will cause a rise in global cirrus coverage unless the upper troposphere dries out or advances in air traffic management and weather forecasting or in aircraft propulsion systems can be used to minimize contrail formation. Scientists are using satellite data and detailed models of the atmosphere to better understand contrail formation and dissipation in order to predict future cirrus coverage and climatic effects. The same models and data are also critical for designing ways to mitigate the climate effects of increased air travel. Perhaps, in the future, vivid atmospheric optical displays will be reserved for natural cirrus clouds and man’s flight will be barely detectable from the ground and from space.

Fig. 1. Persistent spreading contrails at various stages of growth and dissipation over Hampton, Virginia, 10 October 2001.

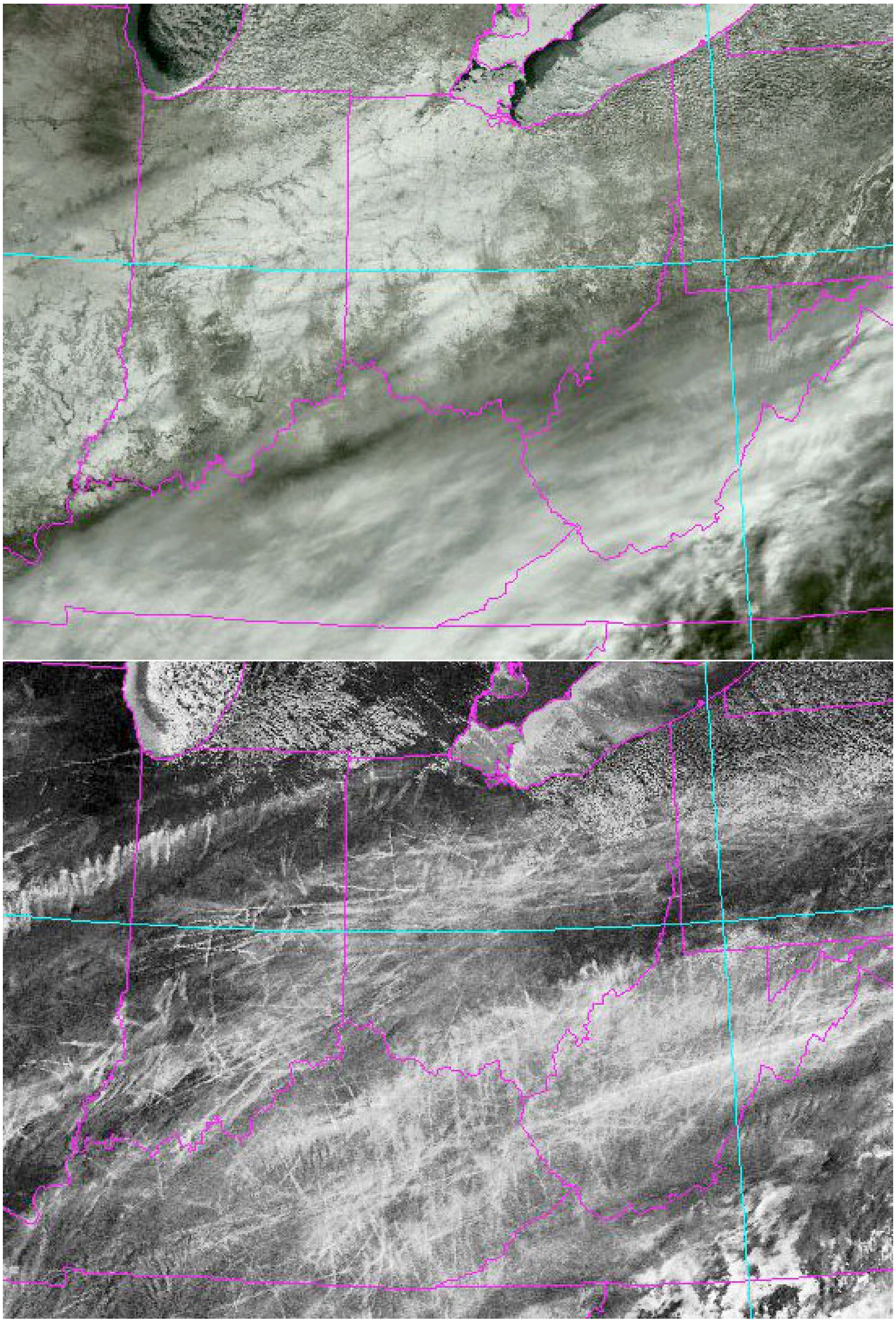
Fig. 2. Contrails are often difficult to see in visible satellite imagery, especially over bright surfaces like deserts, snow, and clouds, because they are often quite thin. Images of the differences in temperatures measured at two different infrared wavelengths are often used to detect persistent contrails not seen in visible imagery. (see below)



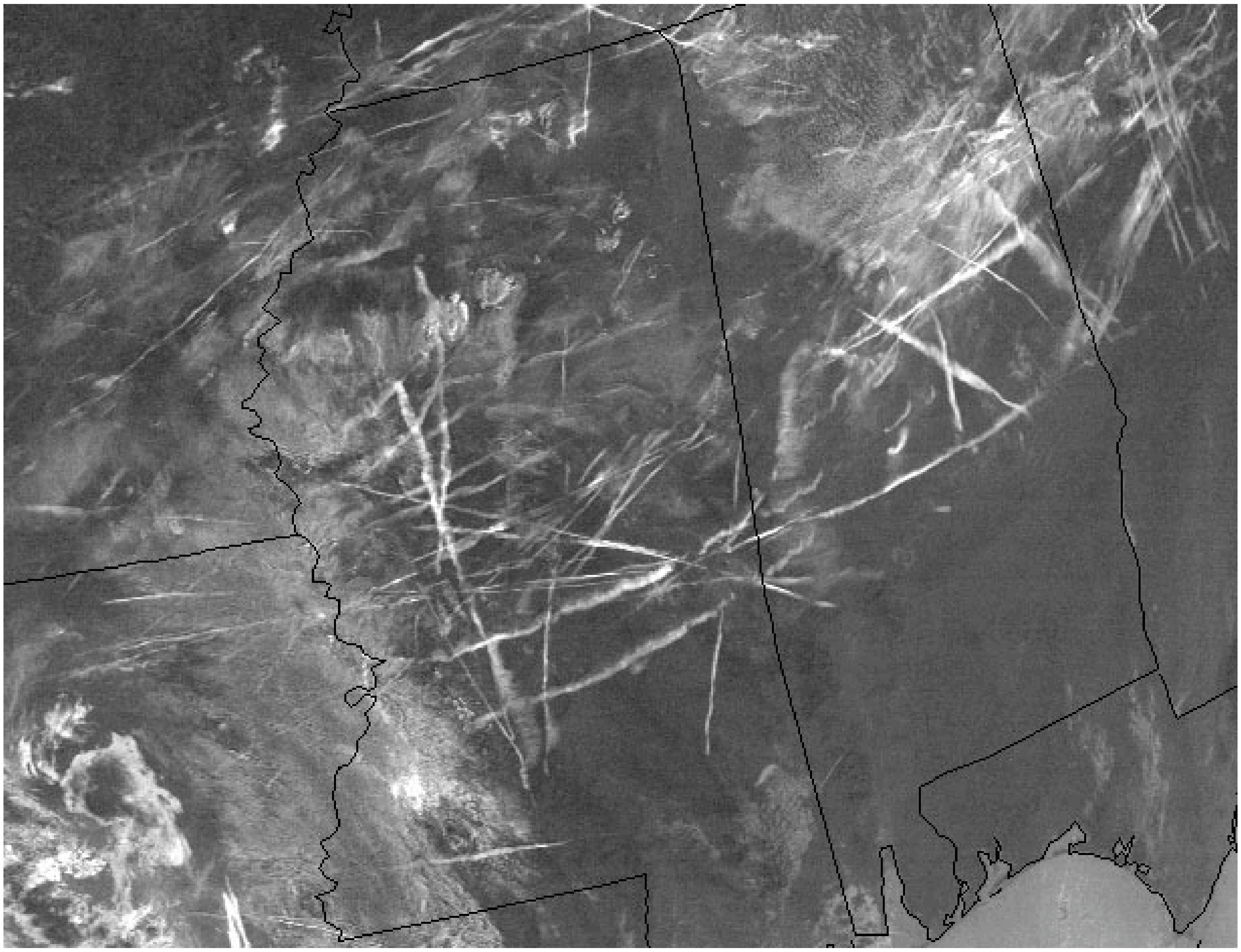
a. Contrails over western USA from Terra MODIS, 19 February 2003.
left: true color, right: temperature difference image



b. Contrails over southwestern USA and northwestern Mexico from Terra MODIS, 23 February 2003.
top: true color, bottom: temperature difference image



c. Contrails and cirrus clouds over snow-covered midwestern USA from Terra MODIS, 25 February 2003.
top: true color, bottom: temperature difference image


d. Infrared temperature difference image from NOAA-15 satellite showing contrails over southeastern USA, 13 November 2001.